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Techniques Employed to Conduct Postshot Drilling at the former Nevada Test Site

W.H. Johnson, J. Cramer, B. Thompson, W. Sitko (Oct. 1966), M. W. Butler (1984), W. D. Dekin (2011)

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FOREWORD

This handbook is a revision of the *Postshot Drilling Handbook*, CODTU-2008-310703, published in January1984 by Michael W. Butler. It was first published in October 1966 as UCID-15034. The original text was written as a joint effort by Walter H. Johnson, Jim Cramer, Bobby Thompson, and Wally Sitko.

This revised handbook provides an outline of the general equipment and procedures used during nuclear testing to recover radiochemical samples from underground nuclear tests. The purpose of the handbook is to familiarize those who have little or no knowledge of the subject with the techniques employed at the former Nevada Test Site (now identified as the Nevada National Security Site).

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1. INTRODUCTION

Postshot drilling provided essential data on the results of the underground nuclear tests conducted at the Nevada Test Site (NTS), now identified as the Nevada National Security Site (NNSS). It was the means by which samples from the zone of interest were obtained for radiochemical analysis. This handbook describes how Lawrence Livermore National Laboratory (LLNL) conducted postshot drilling operations at the NTS, and it provides a general understanding of the process. Postshot drilling is a specialized application of rotary drilling. Accordingly, this handbook gives a brief description of rotary drilling in Section 2 to acquaint the reader with the general subject before proceeding to the specialized techniques used in postshot drilling.

In Section 3, the handbook describes the typical postshot drilling situation at the former NTS and the drilling methods used. Section 4 describes the typical sequence of operations in postshot drilling at the former NTS.

Detailed information on special equipment and techniques is given in a series of appendices (A through F) at the end of the handbook.

2. ROTARY DRILLING

In rotary drilling, the hole was made by rotating a bit (Fig. 1) which ground its way through earth and rock. Since the turning force was normally applied by a machine at the surface, there had to be a rigid connection extending from the surface down to the bit. This rigid connection had to grow in length with the increasing depth of the hole; therefore it was made in sections that could be joined together. Finally, since the bit needed to be cooled and lubricated to operate efficiently, the rigid connection between surface and bit was made of sections of pipe (called joints) to carry fluid to the bit. Besides cooling and lubricating the bit, the fluid performed the additional important functions of carrying the cuttings made by the bit up to the surface and controlling formation pressures. The fluid was pumped down the inside of the pipe and out through the bit to return to the surface in the annular space between the outside of the pipe and the sidewalls of the hole, washing the bit cuttings along with it.

Mechanics of Drilling

Figure 2 is a simplified drawing of a rotary drilling rig. The derrick was a tall, strong structure whose main function was to support the crown block, which had to be able to hold all the weight of the drill pipe and associated equipment; in deep wells this weight may have been more than 1000 tons. The derrick was made tall to provide a place for stacking long lengths of drill pipe, two or three joints to a length, so as to speed up the "round trip" process of taking all the pipe out of the hole and putting it back in again, which was required when a bit wore out and had to be changed.

The traveling block raised and lowered the drill string. Suspended from it by the swivel head was the "kelly," a long hollow shaft, usually square or hexagonal in its outer cross section, which could slide up and down through a similarly shaped hole in the power-driven rotary table. The rotary table turned the kelly, which was fastened to the drill pipe, and thus ultimately turned the bit at the end of the pipe.

To begin drilling, the bit was put directly on the end of the kelly, and a hole was drilled to the length of the kelly, which was somewhat longer than a joint of drill pipe. Then the kelly was raised, a joint of drill pipe was added between it and the bit, and the bit was again lowered into the hole. Drilling continued until the kelly was once more down the hole to its full length; then it was raised and another joint of drill pipe was added. In this way, joint by joint, drilling went on until the desired depth was reached.

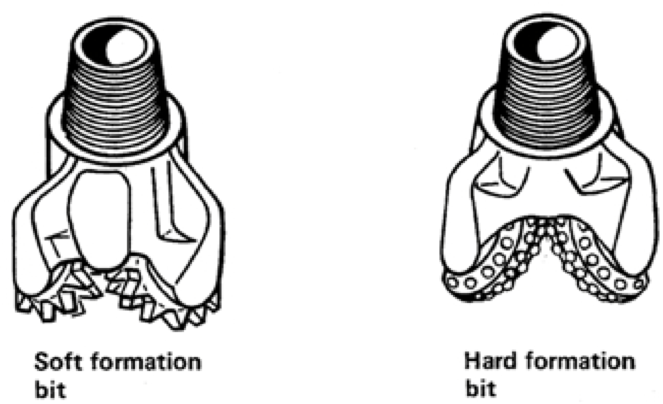

Figure 1. Bits used in rotary drilling

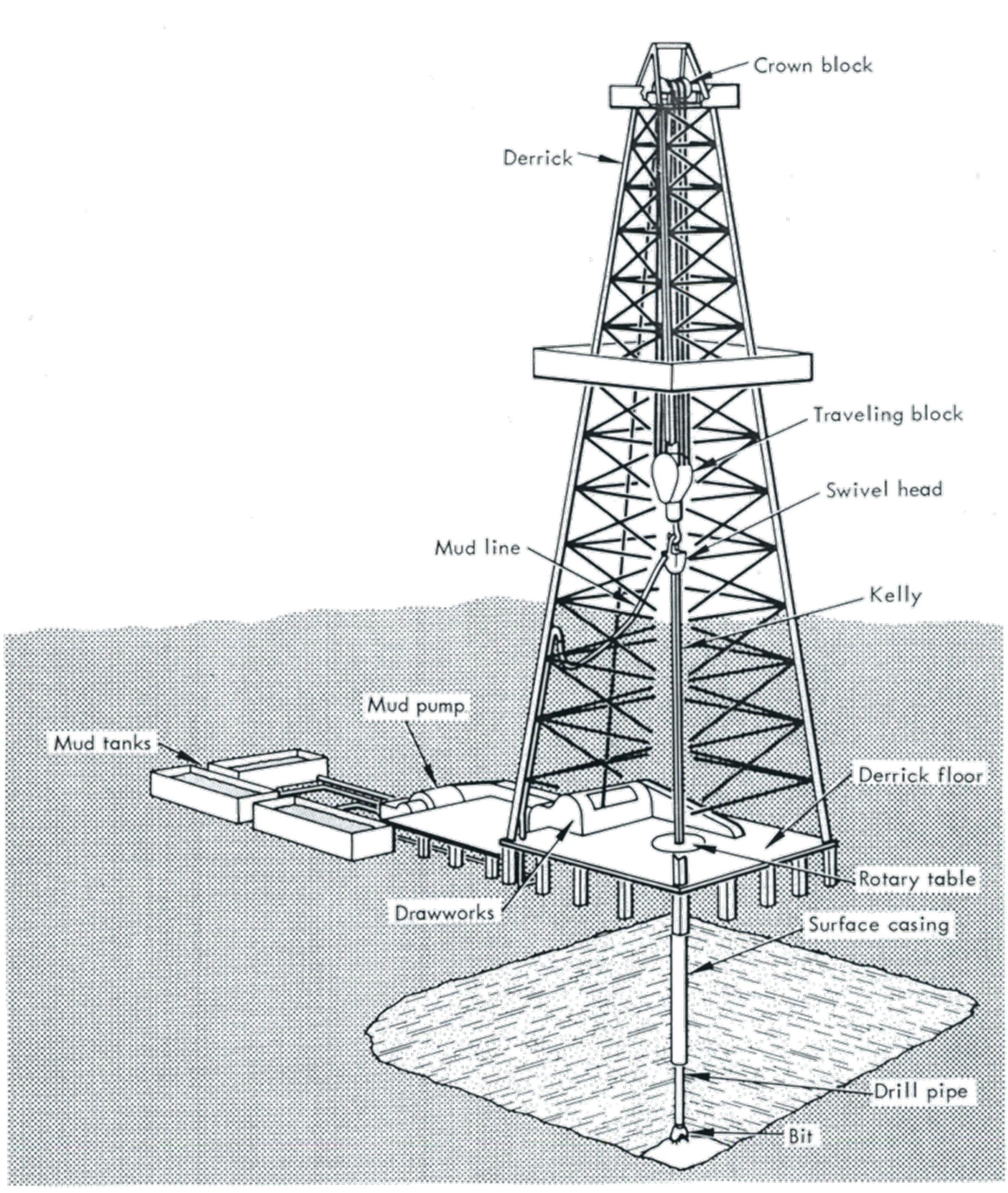

Figure 2. Schematic of a rotary drilling rig.

The Drilling Fluid

In postshot drilling, by contrast, drilling was often done purposely without circulation – without return of the mud to the surface –since the need was not to leave a clean hole, but rather to obtain a few samples near the bottom of the hole and run a logging tool down the inside of the drill pipe. Mud return was especially undesirable when the bit neared the shot zone, because the mud brought unwanted radioactive debris to the surface.

Drilling mud was a water-based fluid carrying various solids in suspension to thicken it. The mud formulation was carefully controlled according to the current drilling situation, and it could be changed frequently during the drilling of a single hole. The mineral bentonite, in suspension, gave the mud the necessary viscosity to carry cuttings to the surface. A dense mineral called barite was added when a heavy mud was desired. Thinning agents such as tannin and caustic soda were added if the mud became too thick. These were just a few of a the wide variety of materials that were used as constituents of drilling mud.

Usually, during drilling, much more power was required to drive the mud pumps than to turn the bits. High pressure had to be maintained together with enough volume of flow to provide an upward mud velocity sufficient to carry the cuttings up and out of the hole.

Under certain drilling conditions, compressed air was a more effective drilling "fluid" than the usual mud. In this application, air compressors replaced the mud pump. Compressed air was fed down through the drill pipe to cool the bit and remove the cuttings from the hole.

Figure 3 illustrates the circulation path of the drilling fluid or “mud.” Maintenance of this mud circulation was essential in oil well drilling because the desired end product was a clean, open hole. When circulation was lost, as when the bit penetrated porous zones where the fluid could leak away into the surrounding formation, efforts were begun immediately to restore it.

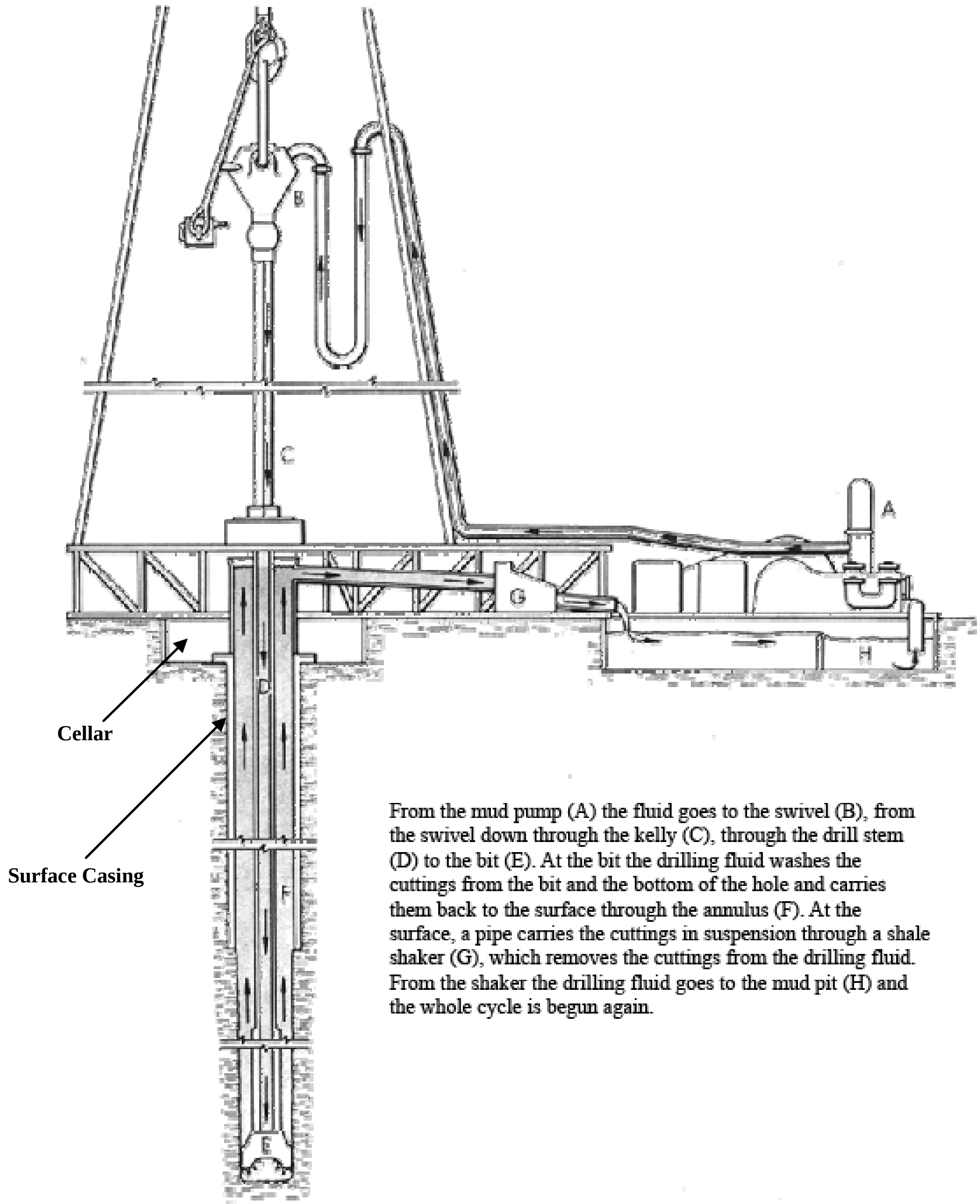

Figure 3. Circulation of drilling fluid.

Directional Drilling

Rotary drilling progressed vertically downward, although holes of any considerable depth (i.e., more than a few hundred feet deep) were likely to deviate somewhat from the vertical. Various devices were available which could be lowered inside the drill pipe to survey the position and orientation of the hole at any depth. These, together with other devices for changing the direction of the hole in a controlled manner, permitted the driller to aim accurately at his underground target, regardless of whether it was directly under the drilling rig or considerably off to the side.

This ability to monitor and control the direction of drilling enabled rigs to drill slanting wells whose bottoms were several thousand feet from their tops.

In postshot drilling, the need for close directional control was critical because target areas were often small.

Surface Casing

Normally the first few hundred feet of the hole were drilled to a larger diameter than the remainder, to permit setting of the surface casing. Steel pipe was cemented in place as a liner for the upper part of the hole. It extended from the surface down through the unconsolidated, near-surface materials to a depth where the sidewalls of the hole were firm enough to stand up without support.

Surface casing kept the hole open through the often unstable zones that lay between the surface and bedrock. In addition, surface casing provided a solid aboveground extension of the hole, to which the blowout preventer could be attached.

Blowout Preventer

In oil well drilling, a hazardous eventuality that had to be guarded against was the blowout. The gushers that were once so much a part of oil drilling were blowouts – oil and mineral gas coming up the hole so fast under subterranean pressure that the flow could not be shut off. Gushers seldom happen now because every rig carries an annular blowout preventer (BOP) that can quickly and effectively seal off the hole if the need should arise.

Figure 4 is a sketch of the containment stack configuration for a postshot drilling operation. It was installed on the casing head, and the drill pipe passed through it going into the hole.

Blowout preventers were especially important in postshot drilling. When the drill penetrated an explosion-produced cavity filled with radioactive gases, the blowout preventer must act instantly to prevent leakage of the gas into the atmosphere.

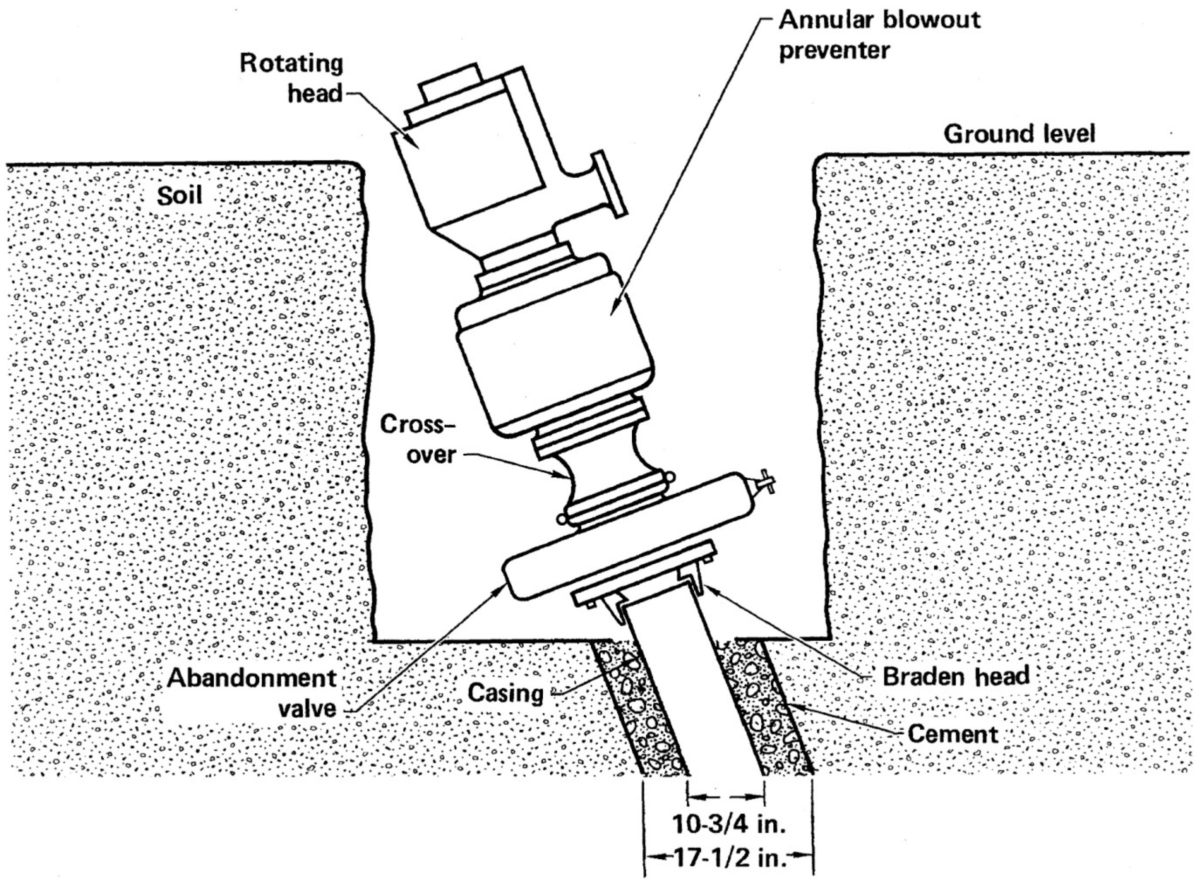

Figure 4. Blowout preventer

3. POSTSHOT DRILLING AT THE FORMER NTS

The typical postshot drilling situation at the former NTS is represented in Figure 5. The zone of interest at the bottom of Figure 5 is the "puddle glass," i.e., the part of the surrounding material which was melted by the explosion and collected in a puddle on the bottom of the cavity, where it cooled and solidified. Obtaining samples of this puddle glass for radiochemical analysis was the primary objective of postshot drilling.

When the shot was detonated a spherical cavity was produced which usually lasted from a few minutes to a few hours, only as long as its internal pressure stayed high enough to support the weight of material above it. When the pressure dropped, the roof of the cavity fell in and initiated a collapse of overlying material, which often carried all the way to the surface where it produced a subsidence crater.

The problem with postshot drilling was to set up the rig as soon after the shot as possible, drill to the zone of interest, and obtain the required samples. Delays were avoided to minimize decay of the short-lived radioactive species in the samples.

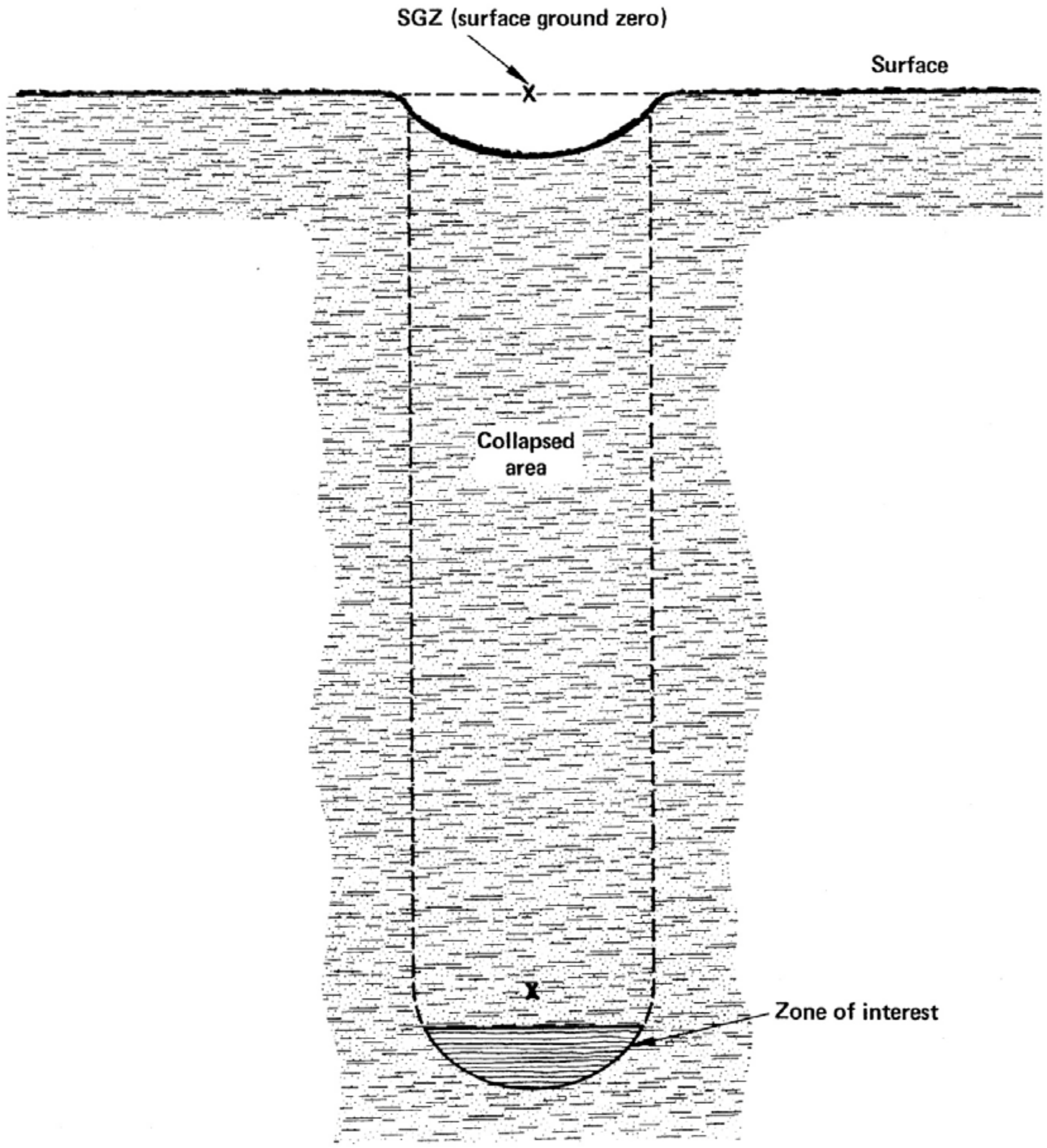

Figure 5. Typical postshot drilling situation at the NTS

Two Methods of Postshot Drilling

Two approaches to the postshot drilling problems were employed at the NTS:

1. Directional hole: A standard vertical drill rig was set up on undisturbed ground outside the collapsed area; the hole was started vertically downward; then directional drilling techniques were used to angle it to the zone of interest.

2. Angle hole: A special rig designed to drill on an angle (the Hycalog) was set up on undisturbed ground outside the collapsed area, and the hole was drilled on an angle directly to the zone of interest.

Figure 6 illustrates these two methods of postshot drilling. Total drill depth and geologic formation normally were the determining factors in deciding which drilling method was used. Normally, depths in excess of 2500 ft (in medium to hard formations) excluded the use of the angle rig. Having the drill rig located outside the collapsed zone on the surface allowed advance preparations to be made before the shot. This arrangement sped up the postshot drilling. For example, the drill rig could be set up before the shot to prepare the cellar, set the surface casing, and make other preparations. After the shot, the drill rig could be set up again quickly since much of the work was already done, and drilling could get underway with minimum delay.

The offset location of the drill rig in the two methods provided another advantage at least as important as the opportunity to make advanced preparations for drilling. It meant that a large part of the hole could be drilled outside the collapsed zone, through undisturbed material where fewer drilling difficulties would be met.

Sidetrack Holes and the Dyna Drill

Two holes through the zone of interest (and hence, two sets of samples from different areas within the zone of interest) could be obtained by making a “sidetrack” hole from the original hole. This offshoot to the original hole was made with a tool called the Dyna Drill, which is described in some detail later in this handbook (see Appendix C).

The Dyna Drill was a directional drilling device which used a “mud motor,” powered by the flow of drilling mud through it, to turn the bit. The drill pipe was not rotated, but merely served as a rigid connection between the drilling rig and the Dyna Drill and was a supply line for the mud that turned the motor.

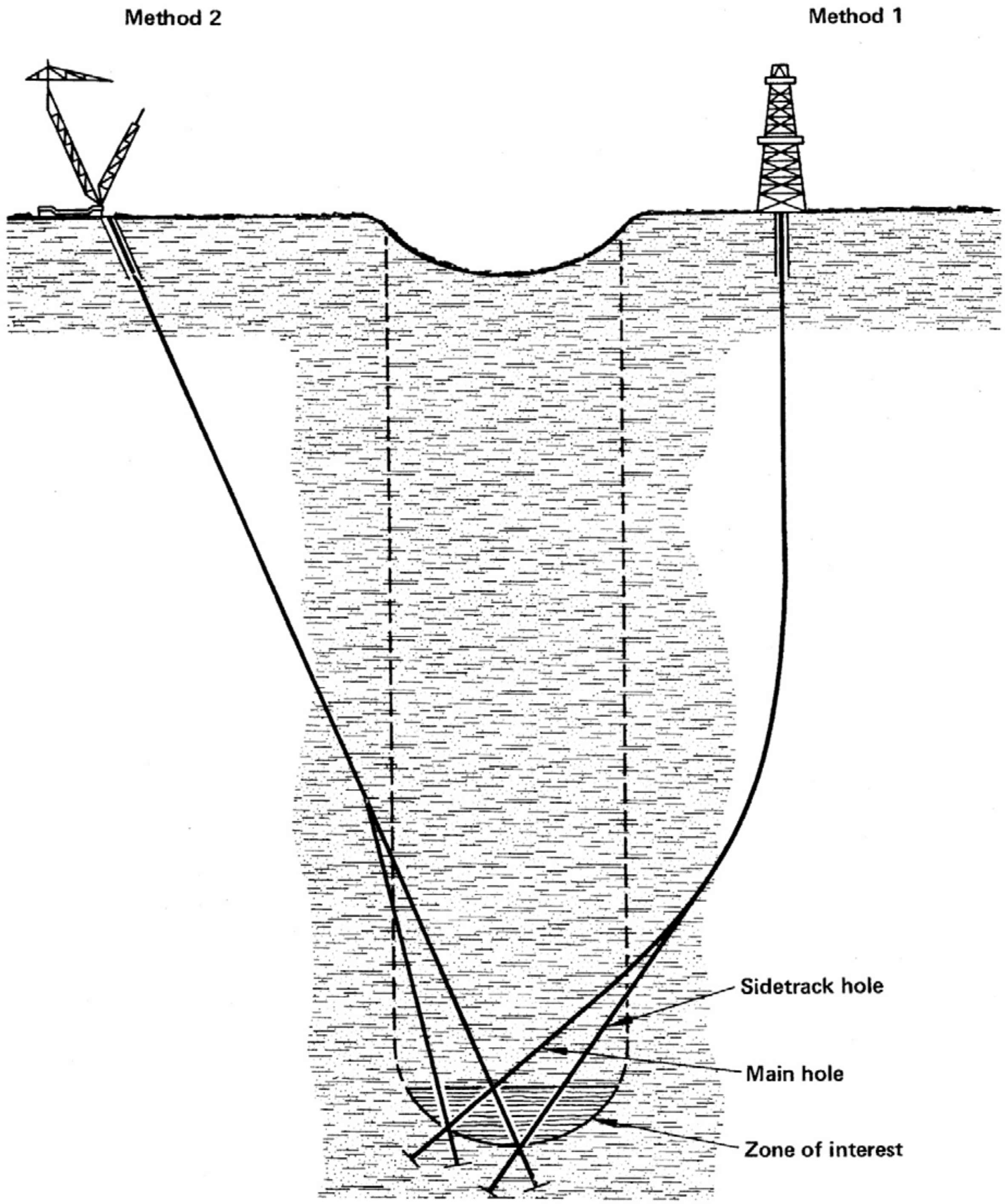

Figure 6. Two methods of postshot drilling at NTS

Obtaining the Samples

When the postshot hole had been drilled through the zone of interest, preparations were made to take puddle glass samples. First, a high intensity gamma-logging tool was lowered through the drill pipe to survey the zone of interest. The LLNL drilling representative examined the log and from it determined the precise depths where samples should be taken.

Samples were taken with a sidewall sampling tool (see Appendix E) which cut into the wall of the hole to obtain cores 1.5 inches in diameter by 6 inches long.

After the original hole was sampled, the drill pipe and tools were withdrawn, and a sidetrack hole was started several hundred feet up in the hole and drilled through another part of the zone of interest. The high-intensity gamma logging and sampling were repeated in the sidetrack hole. On occasion, an alternative directional survey tool was required. Several types of gyroscopic instruments were available for use if such a situation arose.

4. SEQUENCE OF OPERATIONS IN POSTSHOT DRILLING

This section describes the typical sequence of operations in postshot drilling, starting with preparations made before the shot was detonated and ending with the closure of the hole after drilling and sampling were completed. A discussion of the important postshot radiation monitoring which was carried on in conjunction with the drilling is in Appendix G.

Preshot Preparations

To hasten the recovery of samples, it was desirable to make all possible preparations for postshot drilling before the shot was fired so that the drilling could get underway immediately when the area was clear for entry after the shot.

An important consideration in choosing a site for the hole was the predicted location of the zone of interest: the congealed pool of puddle glass which would lie beneath the working point. If an angle hole was to be drilled, it must be placed within range of the target so that once the upper vertical portion was drilled, there would be depth enough remaining to angle the rest of the hole into the target zone.

A cellar to house the containment equipment was excavated and lined with a corrugated metal pipe that prevented the ground from caving in and provided a base for the sliding cover that enclosed the cellar during drilling. The hole was started and drilled deep enough to set and cement the usual 100 to 120 ft. of 10¾ in. casing. The casing was filled with water, and an abandonment valve was installed and closed.

The drilling rig and any auxiliary equipment that might have been damaged by the shock from the shot were moved out of the area before the shot was fired.

Postshot Setup and Drilling

As soon as the area was declared open for postshot drilling, the drilling equipment was moved in.

As drilling progressed, directional surveys were taken every 60 to 120 ft. in both angle and directional holes. Before the target depth was reached, a "trip" was made to bring the bit up and add the sidewall sampling tool. Normal circulation was usually maintained until the bit reached the vicinity of the collapsed zone above the shot. Once circulation was lost, the return valve was closed, and drilling continued without fluid returns.

As previously mentioned, air could be utilized as a drilling fluid. The injection of foam, (consisting of detergent, soda ash, guar gum and bentonite), provided additional lubrication and cooling to the bit and Dyna Drill. Air foam also removed cuttings from the drill hole more efficiently than compressed air alone.

Containment Equipment and Vent Gas System

The containment equipment consisted of four major components: the abandonment valve at the top of the casing, the annular blowout preventer above it, the rotating head, and the vent system. These controlled and contained the escape of radioactive gas or other hazardous materials from the hole at all stages of the drilling operation.

The abandonment valve was designed to close off the hole when the drill pipe was removed, particularly when the drilling operation was finished and the rig moved away. The annular blowout preventer was the main component of the containment system. It totally sealed off gases and fluids in the space between the drill pipe and walls of the containment stack. The rotating head was lined with a thick rubber gasket which surrounded the drill pipe and turned with it, providing a low pressure seal against escaping gas or fluid from the hole while drilling was in progress.

Curving the Hole with the Dyna Drill

Angle holes could drift off course and needed to be corrected, and directional holes were drilled on a curved path intentionally. For both these purposes, as well as for drilling sidetrack holes, the Dyna Drill proved very effective. It changed the direction of the hole with a gentle curve rather than with the abrupt angle characteristic of other hole-deviation techniques.

A description of the Dyna Drill is given in Appendix C.

Sampling

When the total depth (TD) of the hole was reached, a gamma-logging tool was lowered inside the drill pipe to survey the region of interest. (See Appendix D for gamma log description.) The LLNL drilling representative examined the gamma log and from it determined where the samples should be taken. The drill string was then positioned for the first sample; the sidewall tool plug was pulled; and the sampling operation began.

The sampling shoe was forced into the sidewall of the hole to obtain a sample, and then the shoe holder was pulled up the inside of the drill pipe to the surface with a wire line. The shoe containing the sample was unscrewed from the shoe holder; an empty shoe was screwed on; and the assembly was lowered down the drill pipe to take the next sample. As many samples as required were taken and retrieved in this way, one at a time.

A description of the sidewall sampling tool is given in Appendix E.

Closing off the Hole

After all the sampling was completed, the drill pipe was withdrawn, and the abandonment valve closed. The BOP was then removed. The abandonment valve remained on the surface casing until the hole was cemented, and then a cap was welded on top of the casing to seal the hole permanently.

APPENDIX A

Standard Vertical Drill Rig

Figure 7 shows a standard vertical rig in the drilling position. Four or more men were required to operate the rig. The driller was in charge of the rig, controlling the equipment from his console on the derrick floor. A rig superintendent ("tool pusher") was responsible for the overall drilling operation.

During the busiest part of the drilling operation when the entire drill pipe was being removed from the hole to change tools at the bottom end or when the pipe was being put back into the hole two helpers worked on the derrick floor and one helper was stationed in the derrick on the platform. When the driller was hoisting the pipe out of the hole, the two floor men operated slips and breakout tongs that were used to "break" the drill string into stands of two or three joints each. The derrick man guided each stand of pipe to its stacking position, and then unhooked it from the traveling block so the driller could lower the block to bring up another stand of pipe.

Slips were a set of wedge-like devices slipped into the space between the kelly slot in the rotary table and the drill pipe, just below the bulge of a joint, to hold the pipe that was hanging in the hole from falling back when the pipe above the rotary table was unscrewed for stacking on the derrick floor. Breakout tongs were powerful mechanical wrenches for unscrewing the tightly coupled joints of the drill pipe.

When the pipe was being put back in the hole, the operation described above was reversed. The derrick man hooked each stand of pipe to the traveling block so the driller could lower it into the hole. The slips held it in the rotary table until the next stand was screwed into it, and the breakout tongs were used to screw the joints tightly together.

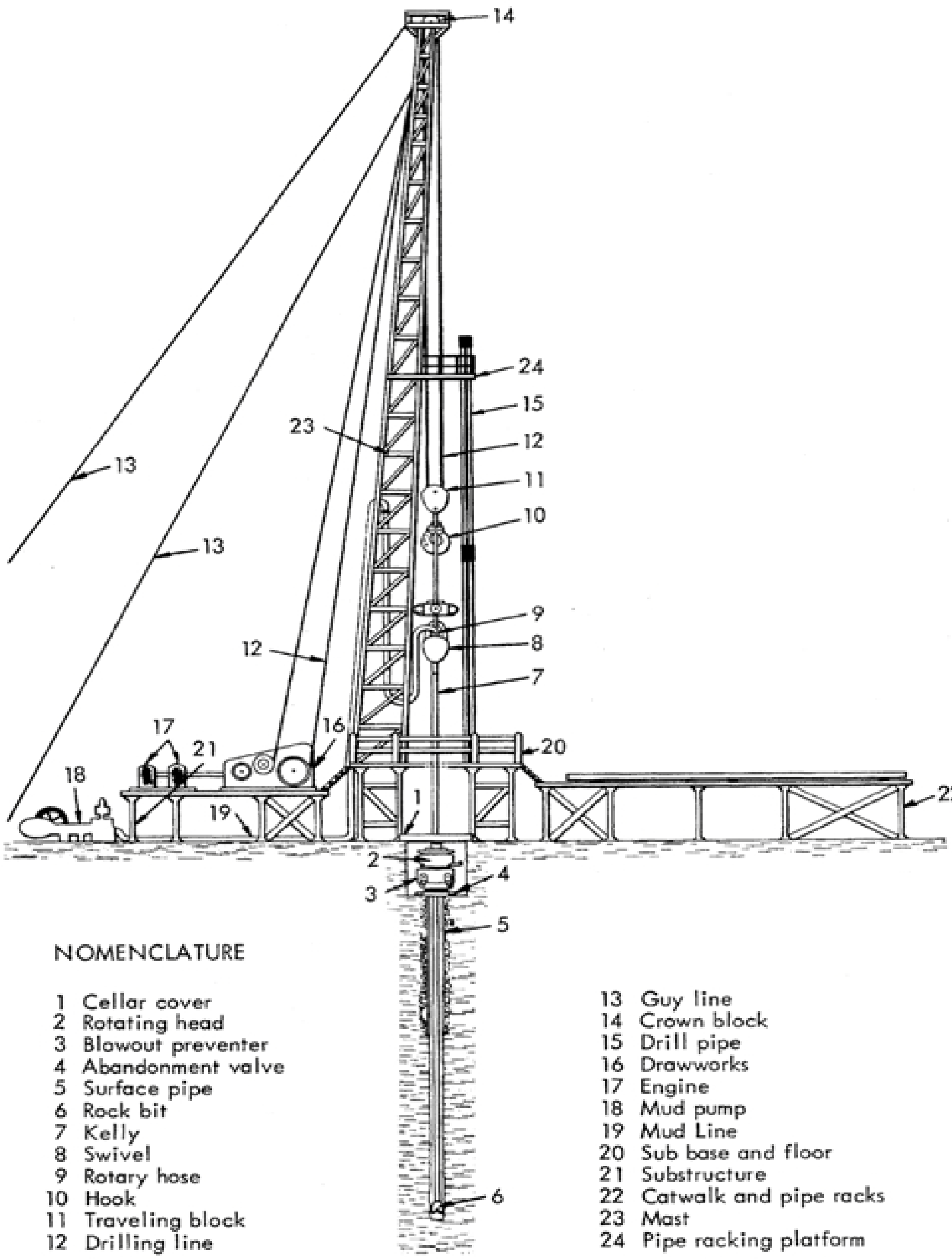

Figure 7. Standard vertical drill rig

APPENDIX B

Hycalog Rig for Angle Drilling

Figure 8 shows a Hycalog slant-drilling rig in drilling position. The Hycalog rig could drill at any angle between vertical and 30° off vertical. Thus, the rig could be set up some distance from surface zero (the distance would depend on depth to sampling zone) safely beyond the range of surface collapse that may follow the shot.

Besides its ability to drill on a slant, the Hycalog rig differed from the standard vertical rig in another important way: a powerful swivel turned the drill pipe rather than a rotary-table-and-kelly arrangement. The swivel was driven by hydraulic power, and the drill pipe fastened directly to it. Since the swivel drive allowed drilling action to continue when the bit was being raised in the hole as well as when it was being lowered, the problem of the drill pipe sticking in the hole was virtually eliminated. This was an advantage the Hycalog rig had over the standard vertical rig.

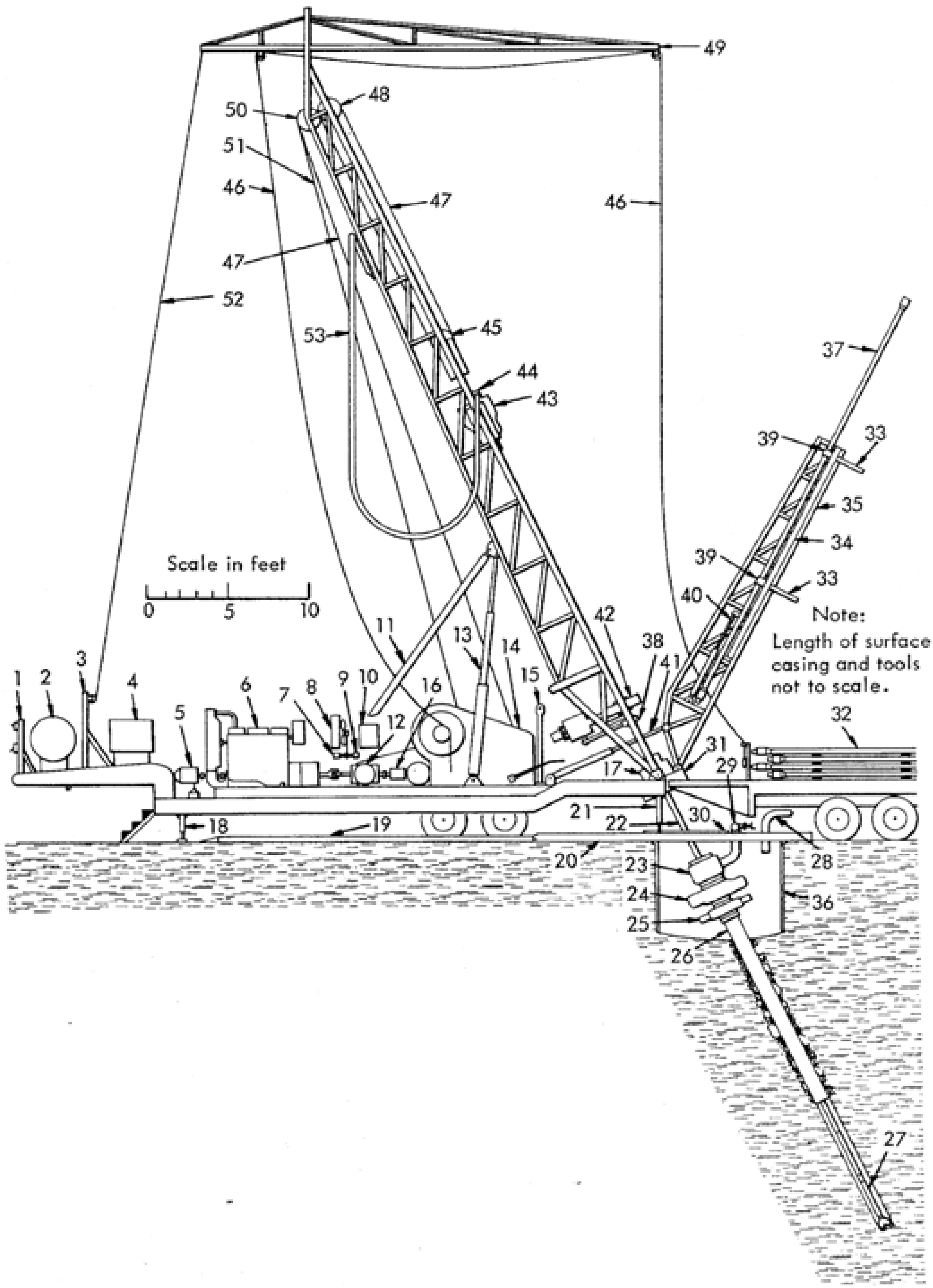

Figure 8. Hycalog angle drill rig

Nomenclature for the Hycalog Rig

1. Fuel tank
2. Electrical panel
3. Derrick lay-down support
4. Main hydraulic reservoir
5. Main hydraulic pump
6. Diesel engine
7. Hydraulic motor
8. Oil cooler
9. Transfer hydraulic pump
10. Auxiliary hydraulic reservoir
11. Derrick still leg
12. 90° angle drive
13. Derrick list cylinder
14. Drawworks
15. Derrick lay-down frame
16. Auxiliary hydraulic pump
17. Spider assembly, pipe slips
18. Trailer support
19. Wheel guides
20. Cellar containment cover
21. Rig stabilizer leg
22. Drill string
23. Rotating head
24. Blowout preventer
25. Abandonment valve
26. 10 ¾ in. surface casing
27. Applicable tools
28. Vacuum vent line
29. Mud return line and valve
30. Sliding cellar doors
31. Derrick base
32. Drill pipe and trailer
33. Pipe clamp hydraulic cylinder
34. Pipe handler carriage
35. Pipe handler frame
36. Cellar casing
37. Drill pipe
38. Backup tongs
39. Pipe clamp
40. Carriage travel hydraulic cylinder
41. Pipe handler hydraulic cylinder
42. Hydraulic-powered pipe breakout tongs
43. Power swivel assembly
44. Poser swivel hydraulic motors
45. Traveling blocks
46. Cat line
47. Drilling line
48. Crown blocks
49. Cat line boom
50. Secondary crown blocks
51. Sand like
52. Boom guy line
53. Represents mud hose and hydraulic pressure returns and drain lines

APPENDIX C

The Dyna Drill and Tool Strings Used With It

The Dyna Drill was a device for turning the bit without turning the drill pipe. Fitted at the bottom of the drill string, it contained a “mud motor” which converted the energy in the pressure-driven drilling mud into rotary motion to turn a drill bit.

Figure 9 shows some of the working parts of the 20-foot Dyna Drill. The mud motor was contained in the upper 11 feet. A specially shaped solid steel shaft mounted eccentrically at both ends was mated with a spiral groove in the thick rubber liner of the motor section in such a way that the mud progressively moved the shaft out of the groove to pass through the motor. This caused the shaft to rotate. The rotary motion of the shaft was transmitted through universal joints to a drive shaft and on to a sub which connected to the bit.

About one gallon of mud had to pass through the motor to produce one revolution of the shaft. The normal mud flow rate for the Dyna Drill was about 350 gal/min. Besides providing power to turn the bit, the mud also performed the usual functions of cooling and lubricating bearings (both in the bit and in the Dyna Drill) and cleared away cuttings from the bottom of the hole with a jetting action.

The main application of the Dyna Drill was in deviating holes (Figure 10). It was attached to the drill string at a small angle chosen according to how sharply the hole was to be deviated.

The azimuth (compass direction) of hole deviation with the Dyna Drill was controlled from the surface by turning the drill pipe until the kick sub points were in the desired direction and then locking the drill pipe so that it could not rotate. Orientation of the hole was checked as required with the usual single-shot surveying instruments.

Tool strings used with the Dyna Drill are shown in Figures 11 and 12. Figure 11 shows the normal Dyna Drill setups with the appropriate subs and Monel collars. Figure 12 shows setups with the sidewall sampling tool.

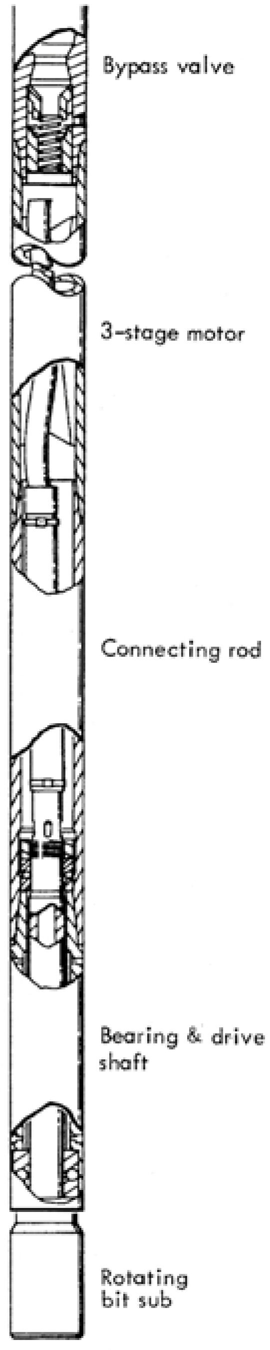

Figure 9. Cutaway view of the Dyna Drill

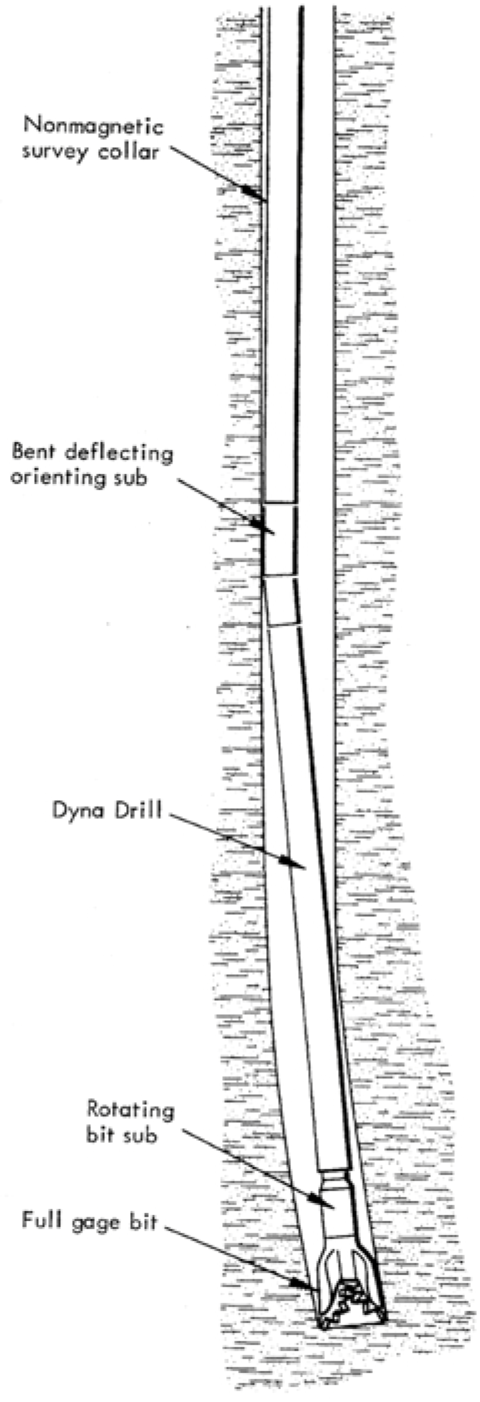

Figure 10. Dyna Drill producing smoothly curved hole

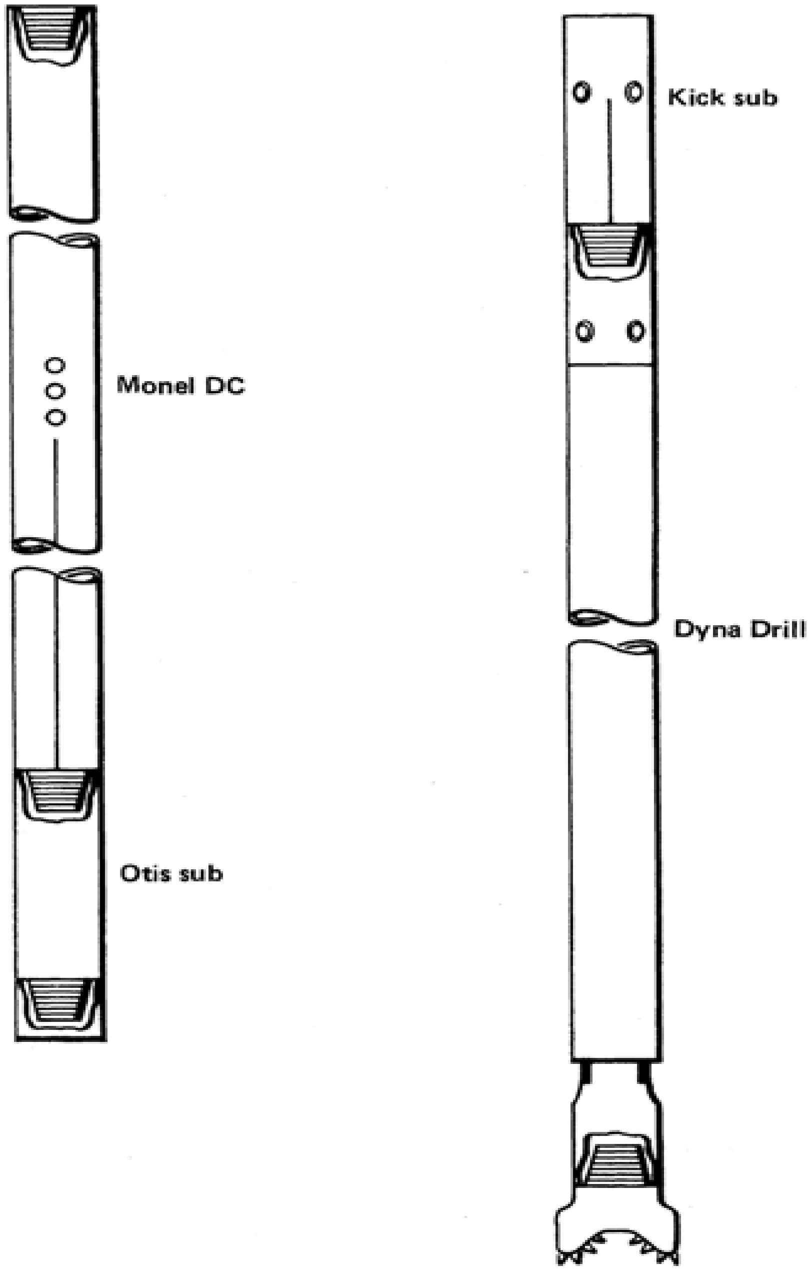

Figure 11. Normal Dyna Drill tool strings

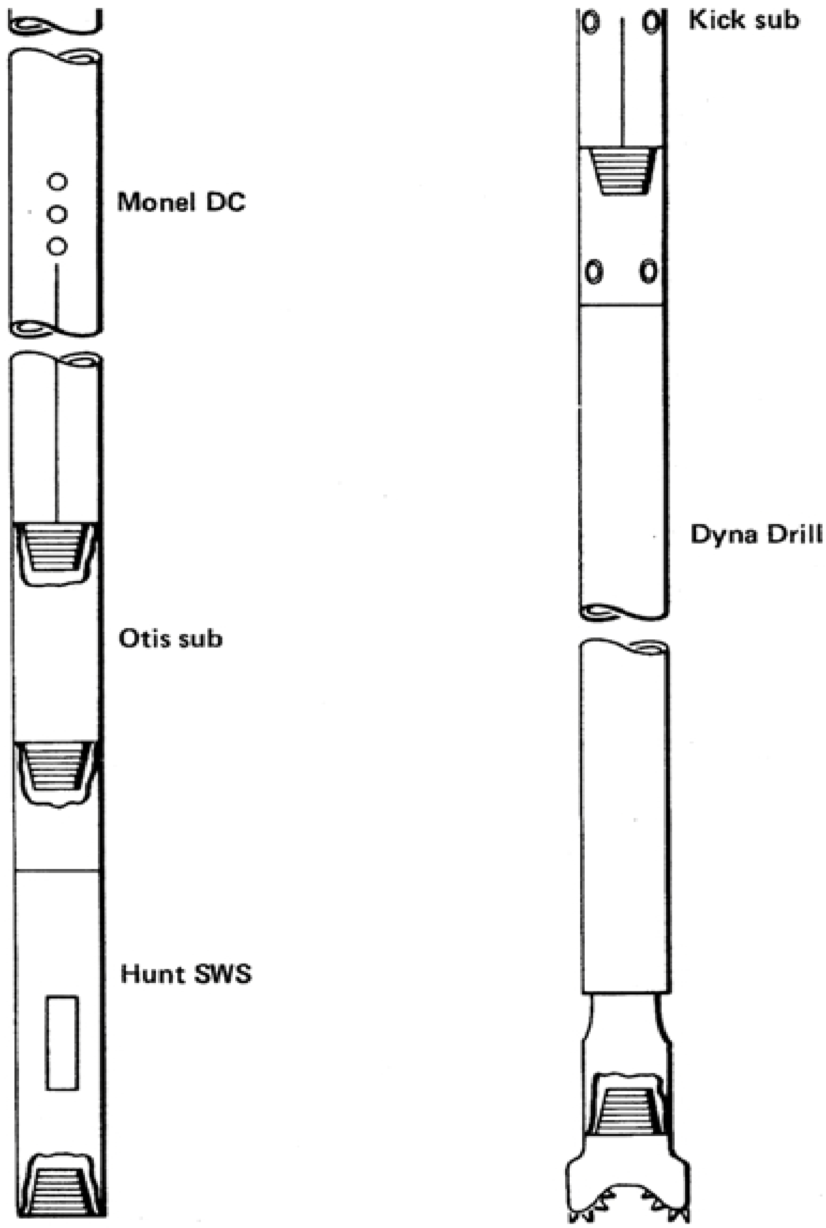

Figure 12. Dyna Drill tool strings used with sidewall sampler

APPENDIX D

The Gamma Log

When the postshot hole had been drilled to its total depth, a device for detecting gamma rays was lowered through the drill pipe to indicate the levels in the zone of interest where radioactivity was highest. These were the places in the hole where samples would be taken for analysis. The portion of the gamma log shown in Figure 13 had five activity peaks which varied in intensity. The LLNL drilling representative selected exact locations for samples to be taken. Figure 13 shows 12 sampling points.

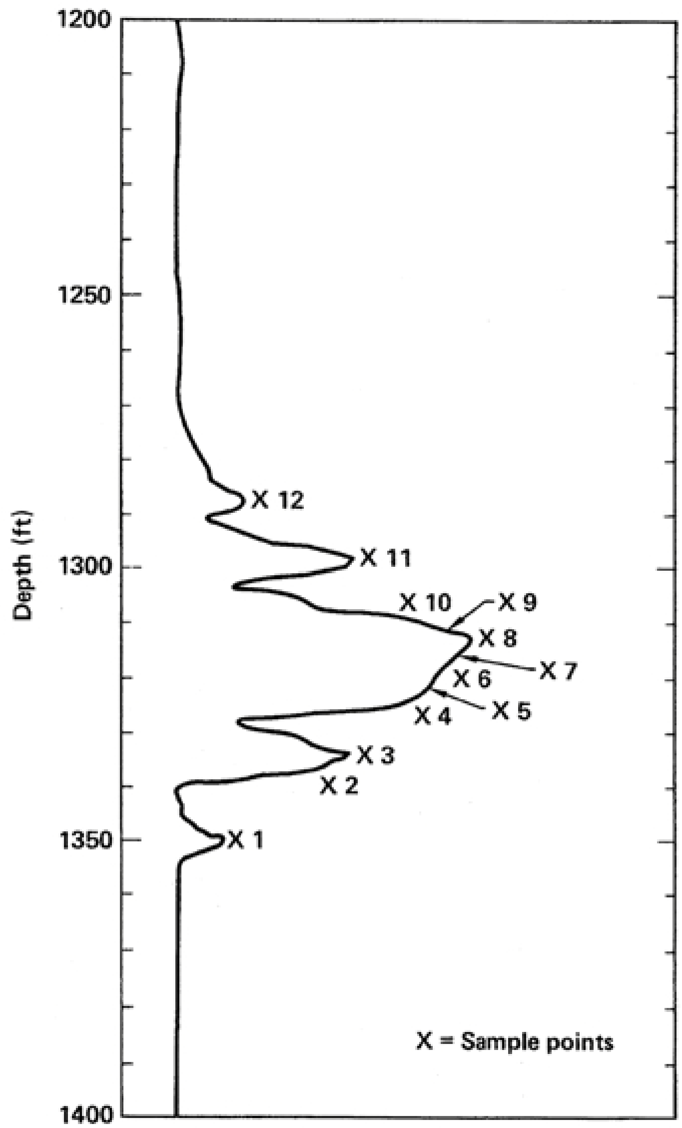

Figure 13. Portion of gamma log showing activity peaks marked for sampling

APPENDIX E

The Sidewall Sampling Tool

Samples from the zone of interest were obtained with the sidewall sampling tool, located above the bit, which removed a 1.5-in. diameter by 6-in. long core of material from the sidewall of the hole. As many core samples as were desired were taken without removing the drill pipe from the hole. When a sample was taken, the shoe tube was brought to the surface by a “wire line” running inside the drill pipe, the core was removed, and the empty core shoe was sent back down inside the pipe to take another sample.

The sidewall sampling tool was designed so that drilling fluid could pass through it to the bit while drilling was in progress. When the drilling was done and sampling depths were determined, the port on the sampling tool was brought to the first sampling depth; the core holder was lowered into place from the surface with the wire line; and a core was taken. In taking a core, the core holder was first pushed into a downward-slanting position against the side of the hole; then the drill pipe was lowered a few inches, which forced the core holder deep into the sidewall of the hole where it cut out the sample. The simplified drawing in Fig. 14 shows the four steps in obtaining a core sample.

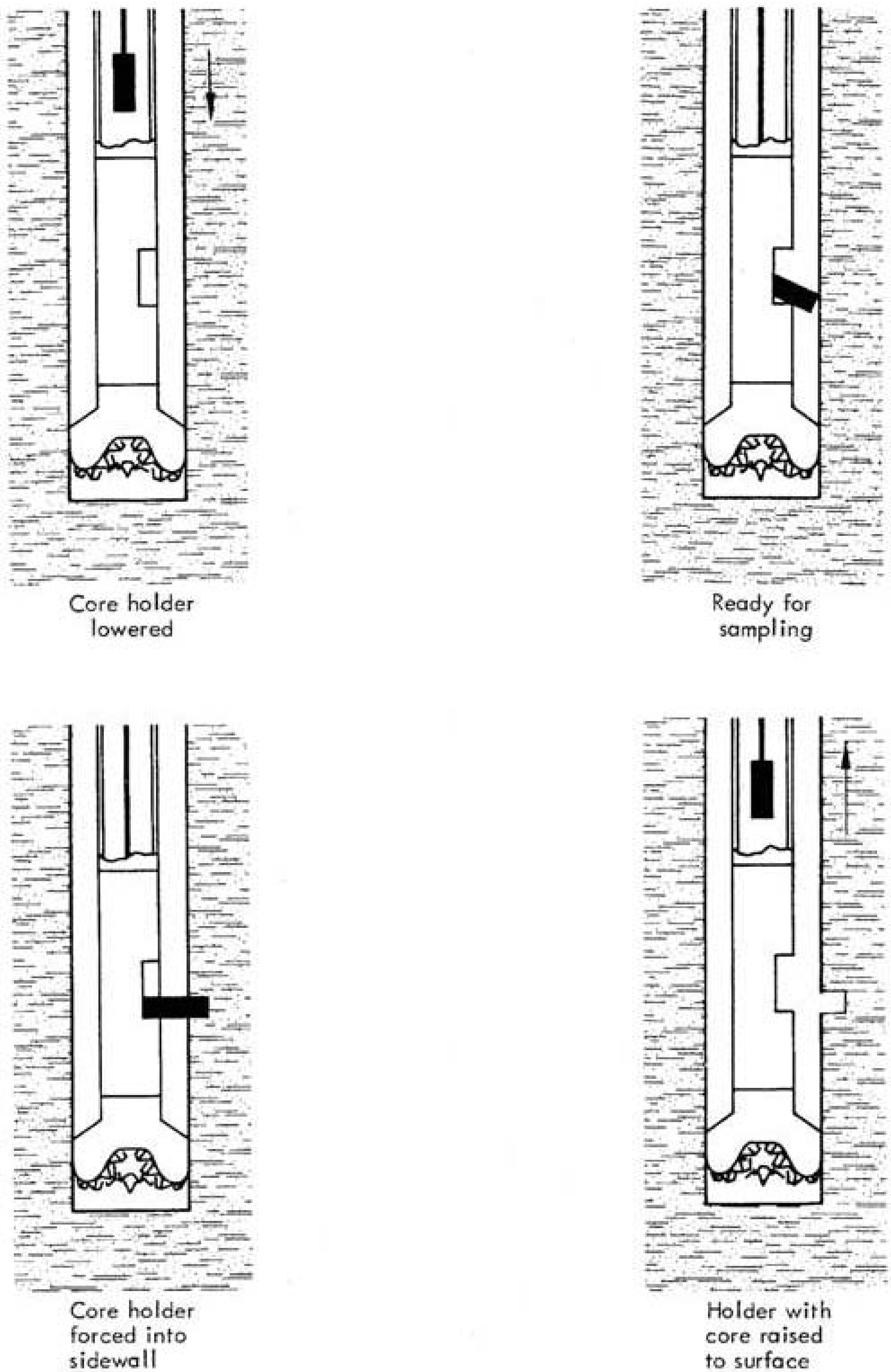

Figure 14. Four steps in taking a sidewall sample

APPENDIX F

Postshot Radiation Monitoring by Environment, Health, and Safety

Protection of personnel from radiological and toxicological hazards was dependent on an effective monitoring program on the drill rigs. The rig monitoring program was divided into two phases: monitoring with portable instruments and monitoring with stationary instruments that either recorded automatically or gave a remote readout at a central observation point.

Monitoring with portable instruments was carried out by Radiological Safety personnel in areas where radiation escape was most likely. Portable monitoring was usually reserved for critical periods of the postshot drilling operation and for checking out possible hazardous situations indicated by the continuously monitoring stationary instruments.

Continuous monitoring of the environmental air on the drill rig platform was accomplished by an array of four air-sampling heads located with one on each corner of the platform. This array was activated when drilling began and was operated continuously until the abandonment valve was closed. The results of this sampling gave an indication of the exposure, if any, experienced by workers on the platform during the drilling operation.

Radiological Safety personnel made continuous surveys of the drill platform and substructures, especially in the vicinity of the blowout preventer. During those surveys, the level of radioactivity, the presence of any toxic gases, and the percentage of any explosive mixtures present were recorded, and if necessary, appropriate mitigating action was taken.

Monitoring with remote readout and automatic stationary instruments was standardized and consisted of the following:

- One RAM (Remote Area Monitor) unit located on the drill platform for monitoring gamma intensities
- One RAM unit located on the mud return line for monitoring gamma intensities
- One gate alarm located on the mud return line near the blowout preventer. This unit was generally set to alarm at some point just above normal background; the alarm was located where it could be easily seen or heard by the driller.